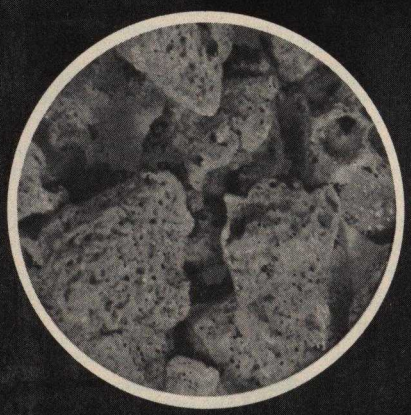
A.I.A. File No. 3-D-3

Slag

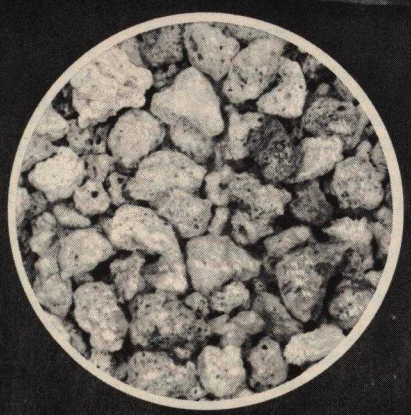
processed blast furnace slag

the all purpose construction aggregate

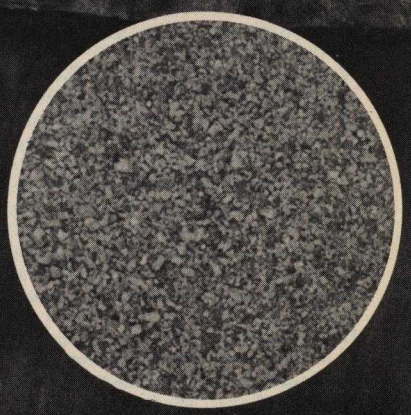
available in the following three types



air cooled



expanded



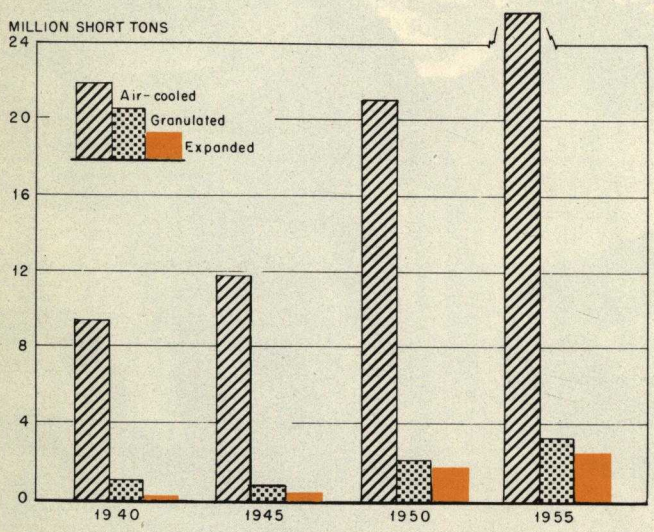
granulated

A.I.A. File No. 3-D-3

NATIONAL SLAG ASSOCIATION

blast furnace Slag

Blast furnace slag, when processed by crushing and selective screening, yields a mineral aggregate which, because of its chemical composition and special physical characteristics, serves to good advantage as a material of construction. Under the present day schedule of steel production in the United States, over 35,000,000 tons of slag are produced annually, hence, it has become recognized as one of our important sources of mineral aggregates. In order that engineers, architects and others might understand and successfully use this by-product of the iron industry, the U. S. Bureau of Mines in cooperation with the National Slag Association published a Bulletin—No. 479—on blast furnace slag which deals rather extensively with production, processing, properties and uses of the commodity. Copies of this Bulletin are available from the Superintendent of Documents, U. S. Government Printing Office.



Increased use of slag as a mineral aggregate in United States.

definition

The American Society for Testing Materials (Serial Designation C125) defines blast furnace slag as "the nonmetallic product consisting essentially of silicates and aluminosilicates of lime, and other bases, which is developed simultaneously with iron in a blast furnace."

types of slag

Molten slag, as coming from the furnaces, when changed to a solidified state, is converted into one of three types of slag known to the trade as: *air-cooled*, *expanded*, and *granulated*. The type of slag produced is dependent upon the manner in which the molten slag is treated or cooled when solidification takes place. In chemical composition there is little difference as to the types, but the physical characteristics—weight, size of particles, structural properties, etc.,—are not at all similar which accounts for the fact that generally different uses in the construction field are recommended for each type. Accordingly, a separate section is devoted to each type on the following pages.

publications and technical releases available through National Slag Association or Member Companies *(see list on back cover)*

slag — general

1. "Iron Blast Furnace Slag; Production, Processing, Properties and Uses." U. S. Bureau of Mines Bulletin No. 479.
2. "Preparation and Properties of Blast Furnace Slag." (N.S.A. 101-18.)
3. "Structure and Mineralogy of Blast Furnace Slags." (N.S.A. 101-18a.)
4. "Properties and Application of Iron Blast Furnace Slag" by J. R. Wallace, P. Fedora and N. D. Weiner. (N.S.A. 154-4.)
5. "Is There Any Corrosive Quality in Slag?" (N.S.A. Symposium No. 10.)
6. "How to Work With Slag Aggregates" by Albert C. Smith. (N.S.A. 156-3.)
7. "Coarse Aggregates; Crushed Stone, Gravel, and Slag"—Simplified Practice Recommendation R163-48—aggregate gradings.
8. "Blast Furnace Slag As Agricultural Liming Material." (N.S.A. 104-42H.)
9. "A Comparison of Blast Furnace Slag and Limestone as a Soil Amendment" by G. W. Volk, R. B. Harding, C. E. Evans. Ohio Agricultural Experiment Station Research Bulletin 708. (N.S.A. 104-42I.)
10. "Airports and Airport Runways." Slag in Airport Construction. (N.S.A. 102-4.)
11. "Report of Investigation of Crushed Blast Furnace Slag as a Medium in Sewage Trickling Filters." (N.S.A. 64-39.)
12. "Design and Performance of an Award Winning Sewage Treatment Plant." (N.S.A. 155-1.)
13. "Specifications for Prepared Stone, Slag and Gravel Ballast." Authorized Reprint from AREA Proceedings, 1944. (N.S.A. 104-9.)
14. "Materials, Surfacing, for Built-Up Bituminous Roofing." (N.S.A. 103-2E.)

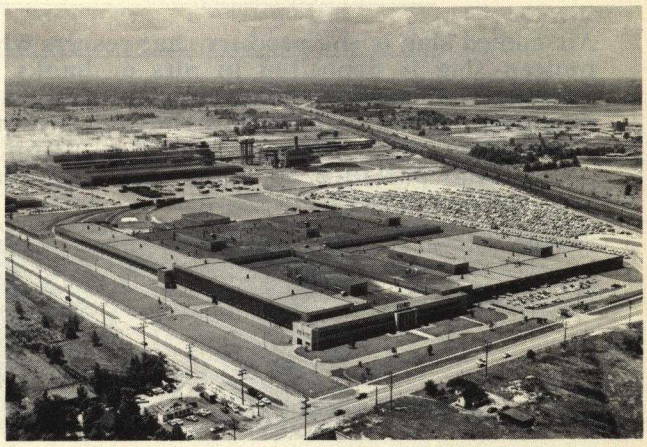
slag in concrete

15. "Materials Required Per Cu. Yd. for Concrete and Cement Mortar."—N.S.A. Concrete Proportioning Tables—Revised, 1955.
16. "Recommended Specification for Portland Cement Concrete." (N.S.A. 155-5.)
17. "Recommended Practice for Selecting Proportions of Concrete." ACI Standard 613-54. (N.S.A. 154-5.)
18. "Blast Furnace Slag as Concrete Aggregate." PCA Technical Release No. ST 2, 1937. (N.S.A. 94-54.)
19. "Blast Furnace Slag as Concrete Aggregate." Report of Committee 201, Aggregate Specifications, American Concrete Institute, 1930. (N.S.A. 72-1.)
20. "Studies on Relation Between Characteristics of Blast-Furnace Slag and Other Coarse Aggregates and the Properties of Resultant Concretes." (N.S.A. 94-7A.)
21. "Relation Between the Abrasion Loss of Blast-Furnace Slag and Its Concrete-Making Properties." (N.S.A. 93-23A.)
22. "Compressive Strength of Slag Concrete." (N.S.A. Symposium No. 18.)
23. "Transverse Strength and Elasticity of Slag Concrete." (N.S.A. Symposium No. 19.)
24. "Bond in Slag Concrete." (N.S.A. Symposium No. 5.)
25. "Heat Transmission of Lightweight Aggregate Concretes." Heat Transmission Coefficients—Expanded Slag included. (N.S.A. 105-37D.)

chemical properties

Blast furnace slag contains four major oxides—silica, alumina, lime, and magnesia—which constitute about 95 per cent of the whole. Minor elements include sulfur, manganese, and iron, with traces of several other elements and compounds. The chemical composition of commercial slag from a given source varies within relatively narrow limits. Analyses of most American blast furnace slags fall within the following range:

	percent
Silica (SiO_2)	33 - 42
Alumina (Al_2O_3)	10 - 16
Lime (CaO)	36 - 45
Magnesia (MgO)	3 - 12
Sulfur (S)	1 - 3
Iron Oxide (FeO)	0.3- 2
Manganese Oxide (MnO)	0.2- 1.5



33,000 cu. yds. of slag concrete used in construction of Ford Motor Company Plant, Brookpark, Ohio.
Architects: Albert Kahn Associates, Detroit
General Contractor: Gus K. Newberg, Chicago

slag industry coordinated through National Association

The National Slag Association is a non-profit organization established and being maintained primarily for the purpose of conducting and stimulating research and investigations in the field of mineral aggregates, with particular emphasis on slag; and to develop, publish, and disseminate factual information pertaining to the production, processing, properties and uses of blast furnace slag.

The Association's Library contains one of the world's largest collections of technical reports and publications dealing with slag. Library courtesies are normally extended to students, engineers, and others interested in the pursuit of information on slag as contained on the printed page.

The Association serves as the spokesman for the Slag Industry with various technical societies and on committees of allied organizations that are interested in developing specifications and test procedures for materials of construction. The offices of the Association, located in Washington, D. C., are, in fact, the clearing house on inquiries pertaining to slag from architects, engineers, contractors, and other interested parties. All requests for information directed to the Headquarters Office are given earnest and prompt attention. Publications and technical releases available through the Association's office are listed below.

26. "Heat Transmission Coefficients for Building Materials." Reprint from A.S.H.V.E. Guide, 1951. Air-cooled and Expanded Slag values included. (N.S.A. 94-52B.)

27. "Blast Furnace Slag in Concrete" by R. H. Bogue. Reprinted from October, 1955 issue, ACI Journal. (N.S.A. 155-8.)

28. "Lengthened Runway is Prepared for Jets." Slag concrete specified because of its greater resistance to heat transfer. (N.S.A. 152-3.)

29. "Slag Used in Manufacture of Large Concrete Pipe." (N.S.A. 105-35.)

30. "Slag Aggregate Used in Manufacture of Reinforced Concrete Pipe, 30-120-in. Diameter" by Wm. H. Quirk, Nov., 1953. (N.S.A. 154-1.)

31. "Slag Concrete Masonry Units."—N.S.A. Manual (revised edition).

32. Underwriters' Laboratory Revised "Standard for Concrete Masonry Units"—4th Edition, Dec., 1953. (N.S.A. 152-6B.)

33. "Relation of Shrinkage to Moisture Content in Concrete Masonry Units." (H.H.F.A. Research Paper 25) (N.S.A. 153-2.)

34. "Bridge Brochure." Slag Used in Construction of Bridges.

35. "Housing Authority Finds Concrete Cheaper." Slag specified in Buffalo, New York, Housing Project for its fire resistance and good workability. (N.S.A. 152-2.)

36. "Durability of Concrete Pavement Experiences in New York State" by E. C. Lawson. (N.S.A. 101-47A.)

37. "Expanded Blast Furnace Slag for Use as Light Weight Concrete Aggregate" by R. W. Miller, Preprint of Paper Before American Iron and Steel Institute Meeting. (N.S.A. 153-3.)

38. "Sydney Foamed Slag as Lightweight Aggregate" by M. R. Foran, Spencer Ball, J. R. Wallace and R. E. Johnson. (N.S.A. 153-3A.)

39. "Design Data for Some Reinforced Lightweight Aggregate Concretes" H.H.F.A. Report 26, Oct., 1953. (N.S.A. 105-37E.)

slag in construction of bases and flexible pavements

40. "Recommended Compositions and Practical Methods for the Design and Control of Hot-Mixed, Hot-Laid Asphaltic Concrete Paving Mixtures"—N.S.A. Bituminous Concrete Tables.

41. "Rolled Slag and Traffic-Bound Roads." (N.S.A. Symposium No. 15.)

42. "Slag-Macadam Base Topped by Hot-Mix." (N.S.A. 105-47.)

43. "Slag Bituminous Surface Treatments on Road Shoulders." (N.S.A. 151-6.)

44. "Granulated Slag in Highway Construction" by C. W. Allen and Fred W. Kimble.

45. "Slag Plays Important Role in Highways" by Charles R. Waters.

46. "Effect of Glassy Slag on the Stability and Resistance to Film Stripping of Bituminous Paving Mixtures." (N.S.A. 102-45.)

47. "Earth-Filled Macadam for Use in Suburbs" by Warren J. Worth, Wayne County Road Commission. (N.S.A. 152-8.)

48. "Heavy Base Lifts for Resurfacing" by Charles R. Waters, District Engineer, New York State Highway Department. (N.S.A. 153-1.)

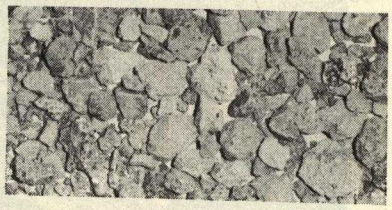
49. "Investigation to Determine the Shear Resistance of Crushed Slag and Stone as Indicated by the California Bearing Ratio Test Procedure." (N.S.A. 155-7-Part 1.)

air-cooled Slag

Air-cooled slag is the product that results when molten slag is deposited in pits or banks for solidification under atmospheric conditions. It may then be further cooled by the application of water. This type is the most widely used and, in commercial parlance, is sometimes designated as "Crushed Slag."

air cooled

Note cubical shaped particles free of flat and elongated pieces.



uses

The excellent performance of slag in all types of work, during the past 35 years, has established it as a high quality all-purpose construction aggregate. The properties of its end uses in portland cement concrete, bituminous mixtures, railroad ballast, etc., are outlined below.

portland cement concrete

Wherever slag is available it is used extensively in all types of concreting operations as the coarse aggregate. Many miles of concrete pavements, numerous concrete buildings—both industrial and office—are constructed of slag concrete. Ready-mix slag concrete is available for prompt delivery from most ready-mix concrete operators located within economical shipping radii of slag plants.

■ **strength**—Slag concrete compares favorably in strength—both compressive and flexural—with that made of other types of high quality aggregates.

■ **weight**—For comparable conditions of quality, slag concrete will weigh approximately 10 lbs. less per cu. ft. than concrete made of other types of aggregates.

Veterans Hospital, Buffalo, N. Y.

Reinforced slag concrete construction completed 1949. Slag selected primarily for its fire-resistant qualities. (Fleisher Engineering and Construction Co.—Contractor.)

■ **bond**—Because of the rough vesicular surface of slag particles, excellent bond is provided between the aggregate and the mortar.

■ **workability**—Due to the rough surface texture of slag particles, it is recommended that the concrete proportions allow for slightly more sand and some more water than is the case when round or smooth surface coarse aggregates are used. When slag is used with air-entraining cements or normal cement with approved air-entraining agents, very satisfactory workability is obtained, hence, it is recommended that air-entrained concrete be used whenever possible. Air-entrainment also materially enhances the ease by which slag can be pumped when construction conditions favor the use of "pumpcrete."

■ **fire resistance**—Slag concrete, on the basis of known tests to determine fire resistance of concrete, has demonstrated its superiority in this respect, and, accordingly, slag is listed in Group I—along with other favored Coarse Aggregates—in the Building Code recommended by the National Board of Fire Underwriters.

Results of recent tests made on a 6″ reinforced concrete slab and beam floor using air-cooled slag aggregate, provide a 4-hour fire rating for this design. Full details of the fire tests are carried in Retardant Report No. 3390-12, October 4, 1954, Underwriters' Laboratories. Tests sponsored by Portland Cement Association.

recommended specifications covering slag for use in concrete

Federal Specification SS-A-281b "Aggregate for Portland-Cement Concrete."

A.S.T.M. Specification C33, "Concrete Aggregates."

A.C.I. 617-51, "Specification for Concrete Pavements and Bases."

A.C.I. "Standard Specifications for Concrete and Reinforced Concrete"—1950 Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete.

A.C.I. 613-54. "Recommended Practice for Selecting Proportions of Concrete."

N.S.A. 155-5. "Recommended Specification for Portland Cement Concrete."

bituminous mixtures

■ **adhesion**—Slag is basically hydrophobic and, hence, provides lasting adhesion for the asphalt. Results of various adhesion tests indicate that slag compares favorably in this respect with calcareous materials.

■ **stability**—Slag aggregate mixes provide highest stability and, hence, softer grades of asphalt can be successfully used with slag than with other types of aggregates whereby much of the stability in the mixture is provided by the bituminous material. Results of laboratory tests conducted by the U. S. Corps of Engineers at Vicksburg, Mississippi, show that stability of slag mixtures is higher than any of those investigated. Because of the high internal friction resulting when slag is compacted in macadam bases, its use for this purpose is recognized, and accordingly is extensively used.

■ **yield**—Slag being characteristically low in specific gravity, it will invariably yield a greater yardage of bituminous mixture for a given unit of weight, than is the case when heavier aggregates are used.

recommended specifications

Federal

SS-C-726a—Crushed-Stone, Crushed-Gravel, and Crushed-Slag; (for) Binder-Course, Sheet Asphalt-Pavement.

SS-C-731a—Crushed-Stone, Crushed-Gravel, and Crushed-Slag; (for) Bituminous-Concrete-Base or Surface-Course.

SS-C-736a—Crushed-Stone, and Crushed-Slag; (for) Bituminous-Macadam-Base or Surface-Course.

SS-C-741a—Crushed-Stone, Crushed-Slag, and Gravel; (for) Bituminous-Surface-Treatment.

SS-S-71a—Sand for Sheet Asphalt or Bituminous Concrete.

A.S.T.M.

D947—Asphaltic Concrete Base and Surface Courses.

D692—Crushed Stone, Crushed Slag, and Gravel for Bituminous Concrete Base and Surface Courses of Pavements.

D693—Crushed Stone and Crushed Slag for Bituminous Macadam Base and Surface Courses of Pavements.

D1073—Fine Aggregates for Sheet Asphalt and Bituminous Concrete Pavements.

A.A.S.H.O.

M63—Crushed Stone, Crushed Slag, and Crushed Gravel for Open-Graded Bituminous Road-Mix Surface Course.

M76—Crushed Stone and Crushed Slag for Bituminous Concrete Base Course.

M78—Crushed Stone and Crushed Slag for Bituminous Macadam Surface Course.

M79—Crushed Stone and Crushed Slag for Bituminous Concrete Surface Course.

penetration and slag base

The same qualities of slag which make it highly desirable for use in bituminous mixture also favor its use for penetration macadam or as slag base in the construction of roads, driveways and parking areas.

railroad ballast

Many of the properties that make slag desirable as a mineral aggregate for use in bituminous mixtures and macadam construction also commend it for service as railroad ballast. Engineers find that when used on high-speed tracks it helps to hold alignment more firmly than by the use of less stable ballast. Another important factor to be considered when using slag is that normally *1 ton of slag yields 1 cu. yd. of ballast in place.*

recommended specifications

Federal Specification SS-C-743, "Railroad Ballast."
A.R.E.A. "Specification for Prepared Slag,Stone and Gravel Ballast."

concrete masonry units

Although most slag used today in the manufacture of concrete blocks is of the expanded type, there is still an appreciable quantity of air-cooled slag being utilized for this purpose. Other than weight of the unit, properties of air-cooled slag block will compare favorably with those made of expanded aggregate. Several fireproofing companies use air-cooled slag extensively for fireproof floor construction of buildings. The Republic Fireproofing Company of New York City promotes a type of floor construction known as the "Republic Slag-blok System." This system has been in use since 1924 and placed in many important building projects throughout the eastern part of the United States. Some of the more important buildings are, as follows:

National Gallery of Art, Washington, D. C.
Waldorf-Astoria Hotel, New York, N. Y.
Temple University Medical Center, Philadelphia, Pa.
Veterans' Hospital, Wilkes-Barre, Pa.
Office & Laboratory Bldg., Wyeth Division, Radnor, Pa.
Y.M.C.A. and Y.W.C.A., Newark, N. J.
Basic Sciences Bldg., New York State Medical Center, Brooklyn, N. Y.
Bldgs. for N. J. State Teachers College, Montclair, N. J.
William Penn Jr. High School, Fairless Hills, Pa.

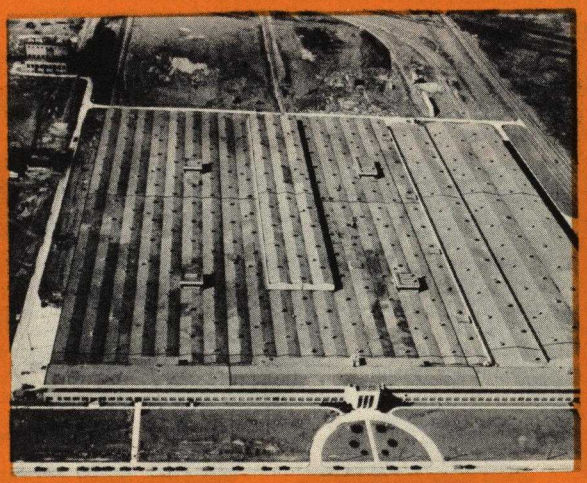
roofing, built-up type

Because of the durability and affinity for bitumen of slag, coupled with its weight differential in contrast to heavier natural aggregates, it has become the principal aggregate for use in built-up roofing in those areas where it is available. Roofing Specifications of the Army and Navy Departments, pertaining to the aggregate item, require that 400 lbs. of gravel, or 300 lbs. of slag, shall be used per 100 sq. ft. This same differential between aggregate types will be found as recommended practice in Catalogs of roofing contractors listed in Sweet's Service.

recommended specifications

U. S. Army Military Spec.—MIL-M—13430, CE 10, May 1954, "Materials, Surfacing, for Built-Up Bituminous Roofing."

Slag-ballasted section of Erie Railroad between Alden and Darien, New York.



Chevrolet Plant, Cleveland, Ohio
Built 1948-1949. 2,850 tons Ohio 6-B Slag applied at rate of 300 lbs. per sq. instead of conventional 400 lbs. when other type aggregates are used, thus lessening roof load by approximately 1000 tons.

trickling filter medium

The vesicular surface of slag particles provides increased surface area essential for efficient filtering, and this property, coupled with a high degree of durability as measured by freezing and thawing tests, assures long and satisfactory service when used as trickling filter media. Selected examples of the many installations where slag was placed as the trickling filter medium are:

Orlando Florida Sewage Disposal Plant, constructed in 1949 and 1950, 8,616 tons of Blast Furnace Slag used. This plant was recently awarded the Annual Sewage Plant Merit Certificate for 1954 by the Florida State Board of Health as being the *best sewage treatment plant of any class*, both from the standpoint of appearance, and operational efficiency. (For details of construction, see Public Works Magazine, December 1954 issue.)

Eslava Creek Sewage Disposal Plant, Mobile, Alabama, constructed in the Fall of 1948, 830 cu. yds. of Blast Furnace Slag used.

Dayton Sewage Plant, Dayton, Ohio, constructed in 1938 and 1939, required 106,000 tons of Blast Furnace Slag.

recommended specifications

Federal Specification SS-C-744a, "Sewage Trickling Filter Media."

characteristics and properties of the aggregate

texture and shape

Air-cooled slag crushes to angular, roughly cubical pieces with a minimum of flat or elongated fragments. The texture ranges from the vesicular pitted surfaces through all degrees of roughness to smooth, conchoidal fractures for the denser slags. The rough vesicular nature of slag gives it a greater surface area than smoother aggregates of equal volume, the feature that provides an excellent key with portland cement and high stability in bituminous mixtures. For macadam and traffic bound road construction, the rough surfaces improve the interlocking of the pieces.

specific gravity

The bulk specific gravity on a dry basis of most crushed and screened slag ranges from 2.0 to 2.5.

weight per cubic foot

The unit weight varies with the specific gravity of the slag, method of measuring, size and grading of the sample. A typical weight of compact, crushed, and screened air-cooled slag, graded as ordinarily used in concrete is usually in the range of 70-85 lbs. per cu. ft. Most specifications for graded aggregates (other than macadam sizes for which the minimum weight is 65 lbs.) require that slag should weigh not less than 70 lbs. per cubic foot when measured dry and compacted.

This characteristic of a comparatively low weight per cubic foot, as compared to other types of aggregate, provides certain economic advantages and in recognition of the fact, construction specifications should allow a weight differential for use of slag and thus assure an equal volume irrespective of the type of aggregate used.

grading

Slag is crushed and screened to conform to the grading requirements of the various State Highway Departments, municipalities, and other specifying bodies. These gradations generally conform with the requirements contained in Simplified Practice Recommendation R163-48. The 24 sizes listed therein provide an aggregate size suitable for almost every type of construction.

absorption

Absorption ranges from 1 to 5%. Although the water calculated as absorption is somewhat higher for slag as compared to other commercial aggregates, the figures obtained may be somewhat misleading since all the water does not enter the pores; some is held in the shallow pits on the surface, and is difficult to determine by standard procedure of surface drying.

durability

Slag is highly resistant to the action of weathering. It will withstand an unusual number of cycles of the sodium sulphate or magnesium sulphate soundness test (ASTM Designation C-88) or freezing and thawing and wetting and drying tests, with little or no effect. High temperatures have very little effect on slag, nor is it disassociated by heat, as it is formed in the blast furnace at about 2700° F. Slag shows a slow and very uniform expansion 0.000006 per degree F., up to its melting point (2100° to 2600° F.). This figure is normally accepted as the coefficient of expansion for cement mortar and steel, hence, slag, when combined with these ingredients, to form reinforced concrete, affords a high degree of compatability.

resistance to abrasion

When tested by the Los Angeles method for abrasion of aggregates, air-cooled slag generally meets the requirements as set forth by state, municipal and governmental agencies; provided, the normal specification limits are generally fixed at a minimum of 40 per cent loss.

non-corrosive

Significant quantities of sulphur in elemental or acid form are never present in processed slag, and while small percentages of sulfides occur, they do not corrode metals. Actually slag is alkaline and alkalinity generally prevents corrosion. The Portland Cement Association has issued a Bulletin—No. ST 2, March, 1937, entitled "Blast Furnace Slag as Concrete Aggregate" wherein the following statement concerning corrosion of slag is carried:

"Corrosion of Steel—The possible corrosion of steel reinforcing due to the sulphur content of slag has caused considerable hesitation on the part of engineers to permit its use. No authentic cases of corrosion of steel due to use of slag aggregate have been discovered. If the concrete is dense and the steel is placed a proper depth below the surface, the steel will have sufficient protection against rusting. The same precautions are necessary for all types of aggregates.

"A number of buildings constructed of slag concrete have been razed to make way for other improvements. Examination of the steel showed that where properly embedded the concrete afforded ample protection. Where any rusting had taken place it was where there was insufficient cover or where poor-quality concrete had been used. Tests made by various investigators show that properly made slag concrete has a protective value against corrosion of steel comparable to concrete made from other aggregates."

National Slag Association
Washington 4, D.C.
613 Perpetual Building

expanded *Slag*
. . . for all types of construction

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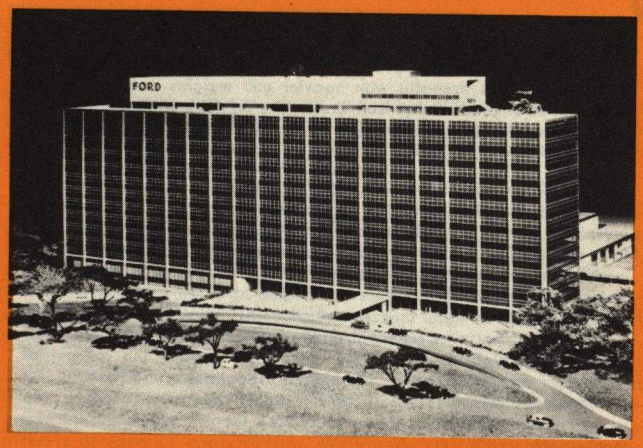
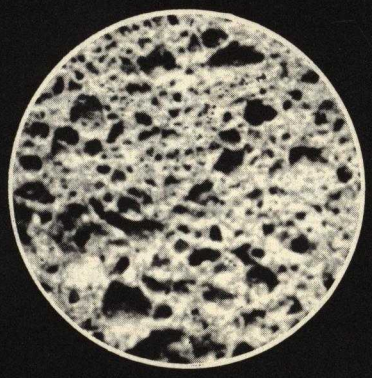


12,700 cu. yds. expanded slag lightweight structural concrete used in construction of the Ford Motor Company Central Staff Office Building, Dearborn, Michigan. Also, air-cooled slag concrete used for fire protection of steel columns and as aggregate in construction of large parking areas. Architects: Skidmore, Owings & Merrill Associates, Architects, New York. Contractor: Bryant & Detwiler Company, Detroit, Michigan.

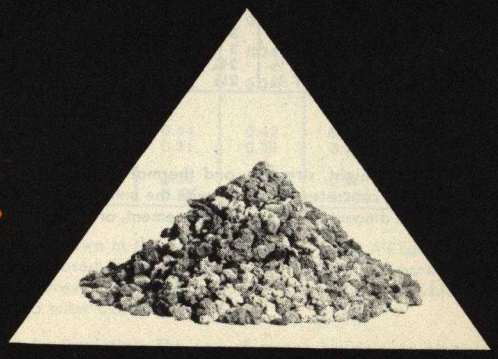
Use of expanded slag concrete in floor slabs and fireproofing of steel columns of the Prudential Insurance Company Building located on Michigan Avenue in Chicago, provided reduction in dead load in excess of 35,000,000 lbs. Architects-Engineers: Naess and Murphy. Contractor: George A. Fuller Company.

The Triumph Corporation, Baltimore, Maryland. The expanded slag concrete masonry units used therein provide durability, strength, fire resistance, thermal properties, attractive color and texture essential in the design of modern industrial buildings. General Contractor: W. H. Sands, Baltimore, Maryland.

Expanded slag concrete masonry units used in construction of St. Christopher Episcopal Church, Detroit, Michigan. Unpainted walls provide attractive appearance through special texture and pleasing color of expanded slag block. Architect: Earl Confers. Contractor: Wm. F. Demske Co., Detroit.



Enlarged aggregate particle showing uniform and complete honeycombed structure of expanded slag in clinker form.



Expanded slag (coarse size) after processing

National Slag Association

expanded Slag

Expanded slag is the cellular product that results from applying a limited quantity of water to molten slag,—less than that required for granulation. Although several methods of expanding the slag may be employed, the characteristics of the finished product are virtually the same so long as gradation and weight per cubic foot are similar. Some expanded slags are identified by trade names such as: "Amlite," "Celocrete," "Enslite," "Expanslag," "Garylite," and "Waylite." Currently 2,600,000 tons, or the equivalent of 3,900,000 cubic yards of expanded slag are produced annually.

uses

Expanded slag, both fine and coarse, is used as aggregate in the manufacture of lightweight concrete for structural purposes and floor fills, concrete products and masonry units. While a much larger percentage is currently being utilized in the manufacture of lightweight concrete blocks, its use as an aggregate for the production of plastic structural concrete is increasing rapidly.

lightweight structural concrete

Lightweight structural concrete made of expanded slag possesses many desirable properties, such as: required strength, outstanding fire resistance, excellent insulating and acoustical values, durability, light weight, pleasing color, low absorption and low cost. Such concrete, when used for fireproofing structural steel columns and for reinforced precast structural members, joists and lintels, will provide a reduction in dead weight up to 35%.

On the basis of field experiences using expanded slag structural concrete, such as the Prudential Building in Chicago, Illinois and the Ford Motor Company Building in Dearborn, Michigan, and an extensive investigation involving the proper concrete proportions to be used with expanded slag for non-reinforced or plain lightweight concrete—to produce various conditions of strength, workability, and resultant weight of concrete— recently completed in the Laboratory of the National Slag Association, the following table of concrete proportions and probable strengths has been developed:

recommended proportions and resultant properties of expanded slag concrete (plain)

proportions by dry loose vol. cu. ft.-per sk.					weight con. dry lbs., cu. ft.	air %	comp. strength psi 28 da.	flex. strength psi 28 da.	thermal values for exp.. slag conc "K" BTU/hr./sq.ft./°F.*
sks. cu. yd.	fine #4–0	coarse ⅜"–#8	nat. sand	blended ⅜"–0					
4	5	2	0	6½	75	20	700	275	2.00
5½	3½	1½	0	4¾	80	18	1300	400	2.20
7	2¾	1¼	0	3¾	85	15	2100	525	2.40
8½	2¼	1	0	3	90	11	2800	625	2.60
7	2½	1¼	¼	3½	86	14	2400	550	
7	2¼	1¼	½	3¼	94	9	2900	575	
7	2	1¼	¾	3	97	9	3000	600	
8½	2¼	1	¼	3	94	8	3400	675	2.78
8½	2	1	½	2¾	97	7	3700	700	
8½	1¾	1	¾	2½	100	7	3900	725	3.00

Notes:

a. The unit weight, strength, and thermal conductivity of expanded slag structural concretes may vary with the unit weight of the expanded slag and the amount of entrained air, cement, or natural sand in the concrete.

b. The heavier expanded slags result in concretes having higher compressive and flexural strengths with heavier unit weights and higher "K" values of heat conductivity. Conversely, the lighter expanded slag will yield better insulating values with lower unit weight of concrete and some reduction in strength.

c. The air content of lightweight concrete as shown is the sum of the entrained air, supplied by either an added air entraining agent or air entraining cement, and the entrapped air normal to the concrete mixture. An increase in the air content results in lighter weight concrete having better insulating properties, with a reduction in strength. A reduction in air content produces a higher strength concrete with an increase in unit weight and a reduction in insulating characteristics. For insulating concretes, where strength is not a vital factor, it is recommended that high air content be used by increasing the amount of added air entraining agent. For higher strength structural concrete, it is recommended that the air content, within the range of desirable workability of the concrete, be reduced by the use of less air entrainment agent.

* Tests conducted by Pittsburgh Testing Laboratories.

■ **reinforced lightweight concrete**—For design data dealing with reinforced lightweight aggregate concrete, a Report published by the Housing and Home Finance Agency entitled "Housing Research Paper 26" affords the following recommendations:

design data for some low-strength lightweight aggregate reinforced concretes

type of aggregate	design strength 28 day P.S.I.	wt. lb./cu. ft.	modulus of elast. P.S.I.	allowable unit stresses					thermal conductivity b.t.u./sq. ft./hr./°F./in.
				direct compressive P.S.I.	flexural compressive P.S.I.	shear P.S.I.	bond, deformed bars: bottom bars P.S.I.	bond, deformed bars: top bars P.S.I.	
*shale	500	72	850,000	125	225	35	75	50	2.25
*shale	1000	74	1,000,000	250	375	50	105	80	2.50
*shale	1500	76	1,150,000	375	525	65	135	110	2.57
pumice	1500	60	700,000	375	450	65	120	85	1.85
*slag	500	75	900,000	125	250	35	85	75	2.10
*slag	1000	80	1,150,000	250	400	50	125	115	2.35
*slag	1500	85	1,400,000	375	550	65	165	155	2.60

* expanded.

Coefficient of thermal expansion of expanded slag concrete in millionth of inch per inch per degree F = 5.0. Volume change due to moisture from saturated to air dry condition for 100 days = 0.05 to 0.09%.

■ **fire resistance**—The excellent fire resistant properties of expanded slag structural concrete have recently been tested under direction of the Portland Cement Association in the form of 4½" reinforced concrete slab and beam floors, in the Laboratories of the Fire Underwriters. A fire resistance rating of 4 hours for this floor thickness was established. Complete results of fire tests are carried in Retardant 3390-7, August 26, 1952, Underwriters' Laboratories, Inc.

concrete masonry units

Concrete masonry units made of expanded slag aggregate possess light weight, durability, strength and other desirable properties required for high quality building construction. The principal properties are detailed in the following sections.

strength—Slag concrete masonry units are readily made to comply with specifications of the American Society for Testing Materials for hollow load-bearing concrete masonry units, Designation C-90, and hollow non-load-bearing masonry units, Designation C-129.

Structural properties of expanded slag block have been investigated by the National Bureau of Standards, and results are reported in Building Materials and Structures, BMS 32.

durability—Masonry units made from slag aggregate, when properly manufactured, are very durable under severe exposure conditions in both above and below ground installations, as well as for interior or exterior construction. Well-made slag units are resistant to shock and can be handled in transportation and on the construction site with minimum breakage. The best evidence of slag block durability is their service performance. Many buildings constructed with these units more than 20 years ago are still in excellent condition.

permeability—Under static head of water it is generally recognized that all concrete masonry walls that are not waterproofed are somewhat permeable to water, both through the face of the concrete and the mortar forming the joints. For that reason, concrete masonry units for underground construction should be waterproofed by approved methods and with materials that will prevent seepage. For construction above ground waterproofing is optional.

Slag concrete masonry units are highly resistant to penetration by rainfall, and the cellular surface texture permits the release and ready evaporation of surface moisture incident to weathering.

shrinkage—It is generally recognized that shrinkage of concrete blocks can be controlled by proper curing and drying of the blocks so that when placed in the wall their moisture content is in equilibrium with the surrounding air. In Housing Research Paper No. 25, H.H.F.A.—which pertains to a report of an extensive investigation undertaken by the University of Toledo on "Relation of Shrinkage to Moisture Content in Concrete Masonry Units"—it is concluded that blocks produced from "cinders, expanded shale, expanded slag and sintered shale tended to show approximately the same shrinkage."

nailability—Expanded or granulated slag units are not only nailable but also nail-holding. For this reason, no special fastening devices or nailing strips are necessary, as baseboards and wooden trim can be nailed directly to the slag units.

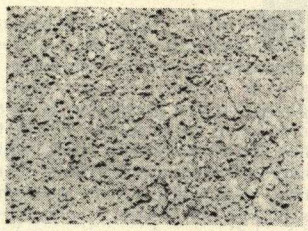
Tests conducted by the Pittsburgh Testing Laboratory on the Holding Power of Nails in Concrete Blocks demonstrate the superior quality of slag block in this respect. Masonry units made with five types of aggregates were tested. A maximum load of 220 pounds in the pull-out test was recorded for slag block, with a maximum load of 275 pounds as holding power. This result was the highest obtained from any of the blocks tested. Cut nails are recommended for use in construction when nailing to the blocks is undertaken.

color—The color of slag masonry units ranges from gray to gray-white, depending upon the type of slag aggregate employed in its manufacture. The cement is a contributing factor in the color of the unit, and as different brands of cement vary in color the blocks manufactured would vary accordingly. Admixtures and plasticizers also have an effect on the color of the resulting unit. Pressure steam curing results in blocks lighter in color than those cured at atmospheric temperature.

Mineral colors added to the lightweight masonry block mixture have created a new integrally colored product, which has been marketed very successfully. The combination of a good mineral color and the pleasing texture of slag blocks makes a product of lasting beauty and high quality. The pleasing, natural tone provided by slag tends to soften the mineral colors added and eliminates the harshness that has been associated with so many colored building materials.

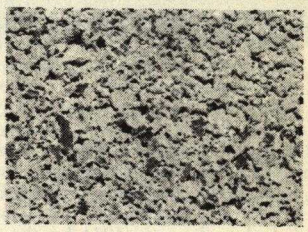
texture—Texture is one of the most important physical characteristics of a concrete masonry unit, because it has a direct effect on the insulating, acoustical, and absorption qualities of the unit. At the time of manufacture, a variety of surface textures ranging from a very fine, close texture to a coarse, open texture may be produced by the proper selection, grading, and proportioning of the slag aggregates.

Coarse or rough textured units are preferred for use as acoustical units where plaster is omitted, as tests indicate a direct relationship between the surface porosity and void characteristics of the masonry units and its sound-absorbent capacity. The coarse-textured units are also generally preferred when stucco is applied as the exterior finish and for interior use when the plaster is applied directly to the masonry wall. The fine textured units are usually specified by architects for use in exposed partition walls of offices or public buildings that are to be painted.



fine texture
(reduced)

recommended where walls are to be painted.



coarse texture
(reduced)

recommended for partitions and walls when sound absorption is important.

sound absorption and noise coefficient—Tests made by the National Bureau of Standards, in the reverberation chamber, on expanded slag blocks—4″x8″x16″—gave a noise coefficient of 0.45.

Recently, tests made at the Riverbank Acoustical Laboratories on expanded slag blocks, for the Celotex Corporation, showed a noise coefficient of 0.45 for the 4-inch open porous units and of 0.70 for the 8-inch open porous units. Other tests made in the so-called "sound box" have shown sound-absorption values of slag units (both of the expanded and air-cooled type) ranging from 20 per cent for dense, fine-textured units to 70 per cent for units with a coarse vesicular surface. The average slag unit may be considered to have sound absorption values of the magnitude ranging from 0.40 to 0.60.

thermal insulation—The thermal insulation properties of expanded slag concrete masonry units are now well established by tests and experiences. Tests conducted in the laboratories of the University of Minnesota, Southern Research Institute, U.S. Bureau of Standards, and others, have provided definite values which can be used with assurance by architects and engineers. The latest "Concrete Masonry Handbook," as published by the Portland Cement Association, lists the following "U" values of expanded slag block for the conditions noted:

coefficients of heat transmission (U) for various walls of expanded slag block

basic wall construction*		interior finish			
			½-in. plaster on		
				¾-in. furring with:	
type	thickness	plain wall no plaster	wall direct	⅜″ plaster-board	½″ rigid insulation
concrete masonry (cores not filled)	8″	0.33	0.32	0.23	0.18
	12″	0.32	0.31	0.23	0.18
concrete masonry (cores filled with insulation)**	8″	0.17	0.17	0.14	0.12
	12″	0.15	0.14	0.12	0.11
cavity walls (with 2″ or larger cavity cavity not filled with insulation)	10″ wall of two 4″ units	0.26	0.24	0.19	0.15
	14″ wall of 4-in. and 8-in. units	0.22	0.21	0.17	0.14
4-in. face brick plus:	4-in. unit	0.44	0.42	0.28	0.21
	8-in. unit	0.31	0.30	0.22	0.17
4-in. common brick plus:	4-in. unit	0.38	0.36	0.26	0.19
	8-in. unit	0.28	0.27	0.20	0.16

* All concrete masonry shown in this table are hollow units. All concrete masonry wall surfaces exposed to the weather have two coats of portland cement base paint. Surfaces of all walls exposed to the weather subject to a wind velocity of 15 miles per hour.

** Values based on dry insulation. The use of vapor barriers or other precautions must be considered to keep insulation dry.

condensation—The insulating value of masonry concrete is directly related to its density or weight per cubic foot. Slag lightweight concrete masonry units have better insulating values, for equal wall thickness, than heavy units hence give greater protection against condensation.

An excellent guide for determining the insulating value of concrete masonry walls is contained in Information Circular CP 68, entitled "How to Calculate Heat Transmission Coefficients and Vapor Condensation Temperatures of Concrete Masonry Walls," published by the Portland Cement Association.

fire resistance—Slag blocks, because of the properties inherent in the aggregate, are more resistant to fire than most other types of masonry units. Slag is formed in the blast furnace at about 2,700° F.; this temperature drives off all volatile or combustible constituents. Numerous fire tests have been conducted on slag blocks, the results of which reveal their superior performance in fire exposure. The first most comprehensive test to determine fire resistance and strength of walls of concrete masonry units conducted in this country was that undertaken by the Portland Cement Association in its research laboratory at Chicago, Ill. Results of this investigation were published in January 1934 by the Portland Cement Association under the title, "Tests of the Fire Resistance and Strength of Walls of Concrete Masonry Units," by Carl A. Menzel. This early investigation included only air-cooled and granulated slag types—not expanded slag. Recently tests conducted on expanded slag masonry units at the Underwriters' Laboratories, Chicago, for the National Slag Association, produced results which permit a 4-hour fire rating for expanded slag blocks as noted.

Comparison of expanded slag block with other types of aggregate, is tabulated on page 6 of the Underwriters' revised "Standard for Concrete Masonry Units." (Dec. 1953)

N.S.A. 152-6A.

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Subject 618 June 12, 1953

BULLETIN

TO: All Manufacturers Operating Under the Inspection And Certificate Service On Concrete Blocks.

". . . The expanded slag aggregates, fine and coarse, shall consist of blast furnace slag in the form of cellular particles appearing in color from white buff to slate or dark gray. The weight of the dry-rodded mixed fine and coarse aggregate shall be not less than 35 nor more than 75 lb. per cubic foot . . .

. . . Blocks eligible for Class B-4 retardants: The face shells in each core hole shall average not less than 1 5/8 in. at the thinnest points. (This may be the average of the two face shells in each core hole.) The end and internal web thicknesses shall be not less than 1 in. at the thinnest points.

. . . A wall assembly of Class D-2 blocks with the core spaces filled completely with loose dry expanded slag aggregate will have a fire endurance period of not less than four hours and our published advices will be revised to include this information . . ."

characteristics and properties of expanded slag

Expanded slag, when processed, readily meets requirements of the American Society for Testing Materials Specifications for Lightweight Aggregates, as follows: for Structural Concrete, Designation C 330; for Concrete Masonry Units, Designation C 331; and for Insulation Concrete, Designation C 332. The more important properties in relation to these uses are detailed below.

texture and shape

Crushed expanded slag is angular and roughly cubical in shape with a minimum of flat or elongated fragments. Due to the action of water and steam during the expanding process, the cellular structure of the aggregate is more pronounced than with the air-cooled type.

specific gravity

The bulk specific gravity of expanded slag pieces may cover a wide range, as is characteristic of all other lightweight aggregates, so this value is seldom, if ever, used in the design of concrete mixtures, hence the value of wt. per cu. ft. is important.

weight per cubic foot

The loose weight of expanded slag, dependent upon the source ranges between 35 to 70 lbs. per cubic foot for the fine aggregate, and from 30 to 55 lbs. per cubic foot for the coarse aggregate. The weight per cubic foot when blended, is governed by the proportion of coarse to fine aggregate.

grading

Expanded slag is normally produced in two sizes: the coarse ranging from ½" to No. 4 sieve; and the fine from No. 4 sieve to 0.

thermal conductivity

Values for thermal conductivity—K, equals Btu/hr/ft²/°F/in.—have been determined for both fine and coarse expanded slag in the laboratories of the Southern Research Institute. The hot plate apparatus was used and tests were conducted in accordance with A.S.T.M. C 177-45. The low K values obtained (reported below), together with the relatively low cost of the commodity on the open market, would indicate that expanded slag should receive more recognition as an excellent loose fill insulating material by itself as well as the concrete products wherein it is used as the aggregate. (See U values for core-filled blocks on page 9.)

Fine Expanded Slag (½" to dust), Wt. 60 lbs./cu. ft.

Mean Temp. ° F.	Thermal Conductivity Btu/hr/ft²/°F/in.
103.3	1.16
112	1.25
121.4	1.32
124	1.42

Coarse Expanded Slag (½" to No. 4), Wt. 40 lbs./cu. ft.

92.9	0.77
100.9	0.78
120.4	0.96

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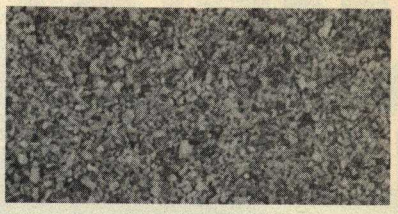
granulated Slag

Granulated slag is the granular product formed when molten slag is suddenly chilled by immersion in water. Under present conditions, many of the blast furnace operators do not granulate their slag, hence, this type is currently available only in the Chicago, Cleveland, Youngstown, Pittsburgh and Buffalo areas.

granulated

Rapid conversion from the molten state to a water-quenched product develops a rather fine-grained granular slag.



uses

in manufacture of cement

Three types of cement are currently being manufactured from granulated slag. These are: portland cement, portland blast furnace slag cement and slag cement.

Portland cement (ASTM Specifications C 150 and C 175) employs granulated slag as a source of raw material.

Portland blast furnace slag cement (ASTM Specification C 205) is made by intergrinding portland cement clinker with granulated slag. Many cement manufacturers have added portland blast furnace slag cement to their product lines during the past ten years, hence, it is now available over wide areas.

Slag cement (sometimes referred to as pozzolanic slag cement) is a product wherein the principal ingredient is granulated slag. In some instances lime is added and in others, only an air-entraining agent is interground during the manufacturing process. It is used principally as an admixture and adds considerably to the workability of the concrete and provides a lower heat of hydration. The principal brands produced by this process are known as Darag (produced in Buffalo, New York) and Magnolia (produced in Birmingham, Alabama). Trief Cement, which has been used extensively in Europe, particularly for large dam construction, is made by grinding wet granulated slag to a slurry, to which portland cement in amount of approximately 15% of the solids is added and sometimes a small amount of the alkali salts of sodium or potassium may be added as an accelerator. The grinding equipment is set up at the site of construction, and the moisture in the wet ground cement acts as part of the mixing water of the concrete.

base material for pavements

Wherever granulated slag is available, it is being used extensively as an excellent base material for pavements, runways, parking areas, etc. Many miles of the recently constructed Ohio Turnpike have a compacted 6″ base of granulated slag.

concrete masonry units

In certain areas appreciable quantities of processed granulated slag are used in the manufacture of concrete masonry units—the resultant product, excepting texture and weight, possesses most of the properties contained in blocks manufactured of expanded slag.

floor fill

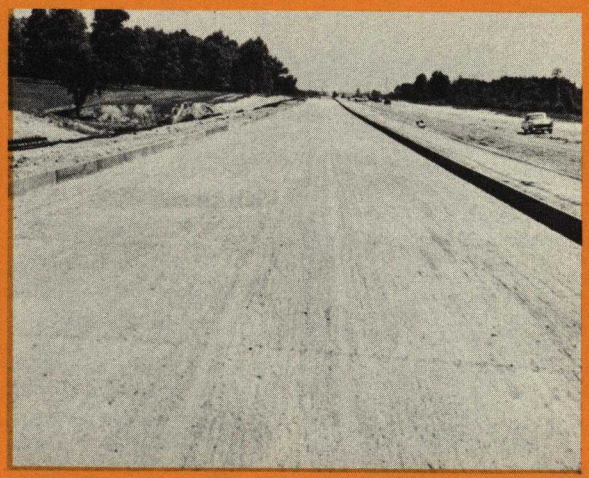
It can be used as fine aggregate along with air-cooled slag, as the coarse aggregate to provide an excellent concrete for floor fill. Many of the floors in the new Equitable Life office building constructed in downtown Pittsburgh employed this type of concrete. (The September 1953 issue of Civil Engineering Magazine contains an interesting write-up of the design factors of these buildings).

in landscaping and agriculture

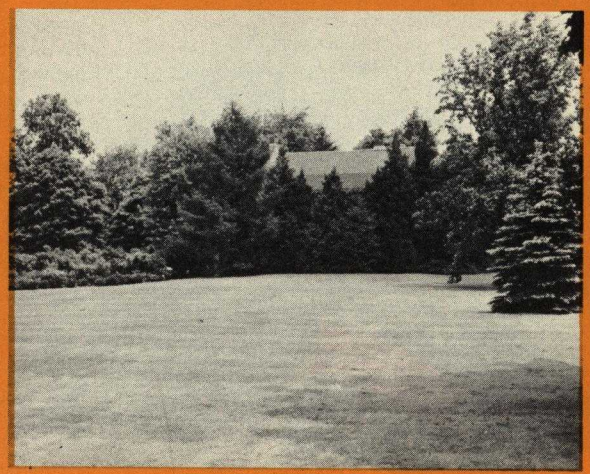
Granulated slag as well as fine air-cooled slag is used widely as an agricultural liming material and for soil conditioning in architectural landscaping.

It not only neutralizes soil acids through the effective liming action of its silicates and alumino-silicates of lime and magnesia, but also contains many minor elements such as manganese, titanium, sulphur and boron which stimulates the growth of grasses and other plants to a phenominal degree. One agronomist writes, "I have seen some results with this material which approach a miracle."

Agricultural slag is approved by Federal Agricultural Agencies, as well as being licensed by various State Departments of Agriculture. It is economically available in many locations where blast furnaces are in operation.



Large quantities of granulated slag used on the Ohio Turnpike as base material. Above photo shows section with granulated slag base ready to receive concrete for the pavement.



Agricultural Slag for landscaping, showing effectiveness of slag treated lawns.

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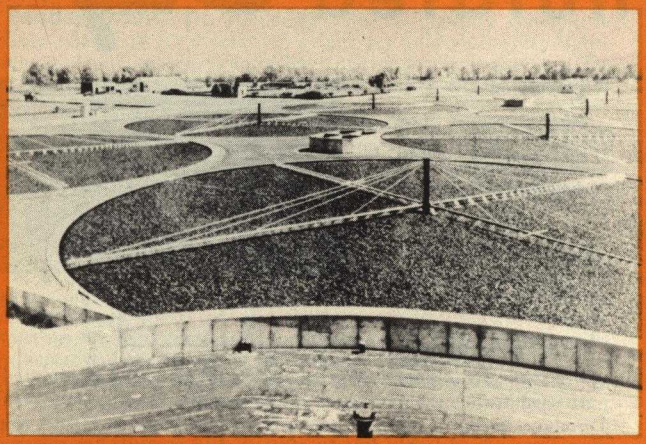
Slag for all types of construction



Although constructed in 1938, the slag trickling filter beds of the Dayton, Ohio Sewage Plant are serving efficiently today. 1,960 railroad cars of slag were required to fill the 20 beds comprising the system.

Nottingham Reservoir—fully enclosed—built for city of Cleveland, employed 30,000 cubic yards of slag concrete. Reservoir has capacity of 25,000,000 gallons of water for domestic consumption.

member companies of the National Slag Association with official representatives

ALABAMA

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Birmingham Slag Company *
P. O. Drawer 155—4-3361
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C. A. Barinowski, Vice President
W. C. Ireland, Vice President

United States Pipe & Foundry Co.*
3300 First Avenue North—3-3161
Fred Osborne, Vice President

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P. O. Box 1432—LI 3-1341
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Gary Slag Corporation *
P. O. Box 444
R. J. Graham, Vice President

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Maryland Slag Company
Pier 2, Pratt Street—Plaza 2-7120
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Edward C. Levy, President

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The Buffalo Slag Company, Inc.
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H. N. Snyder, President

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Callanan Slag and Materials Co.
Foot of Monroe St.—Ashley 4-3422
J. R. Callanan, President

OHIO

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American Steel and Wire Division
United States Steel Corporation
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G. M. Lakins, Dist. Representative

Cleveland Slag Division *
Standard Slag Co.
414 Fidelity Bldg.—Cherry 1-7540
A. W. Wood, General Manager

Hamilton

American Materials Corporation *
P.O. Box No. 291—4-8373
Walter B. Evans, Jr., Manager

Lorain

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Cleveland, Ohio
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National Tube Division
United States Steel Corporation
209 Broadway Bldg.—5-6897
Charles E. Fell, Dist. Representative

Youngstown

Midland Slag Company
1200 Wick Bldg.—Riverside 3-3151
Fred Hubbard, Consulting Engineer

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Rittenhouse 6-3900
Irving Warner, Jr., Manager

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Duquesne Slag Products Company *
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R. O. Dierker, President

United States Steel Corporation
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Express 1-2345
R. K. Plumb, Manager, Slag Sales

Sharon

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Fred Hubbard, Consulting Engineer

K. L. Dunbar Slag Company
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K. L. Dunbar, President

Swedeland

Philadelphia Slag Company
Division of The Adams Products Corp.
River Road—Broadway 2-2643
Edwin S. Malmed, Manager

TEXAS

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412 Texas Bank Bldg.—Prospect 8194
J. Rutledge Hill, President

Houston

Houston Slag Materials Company
706 Scanlan Building—Capital 3-4409
George W. Lanier, Vice Pres.
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FOREIGN

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Sydney, Nova Scotia

Dominion Steel and Coal Corp. Ltd. *
Dept. of Research and Develop't—5471
J. R. Wallace, Chief Metallurgist

Matlock, Derbyshire, England

The Five Towns Macadam Co. Ltd.—
Matlock 741
John Hadfield, Chm. & Joint Mng. Dir.

* Indicates Companies also processing Expanded Slag.

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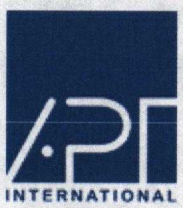

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